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5.1: Numerical Models of Mode Interaction in Gyrotrons: Capabilities and Limitations *

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Abstract: *Mode interaction in cylindrical and coaxial gyrotrons are simulated by gyrotron design code MAGY. Effectiveness and limitations of MAGY models for mode interaction in gyrotrons operating at higher order modes are discussed. Similarities and differences in mode competition process in cylindrical and coaxial gyrotrons are studied and discussed.*

Keywords: high power gyrotrons; coaxial gyrotrons; mode competition; numerical modeling

Introduction

High power gyrotrons operating in long pulse or continuous-wave (CW) regimes are based on interaction between an electron beam and at a RF field of high order mode. For example, the 170 GHz gyrotron developed at FZK Center, Germany operates at $TE_{34,19}$ mode [1]. Operation at high order modes increases possibility of excitation of several modes capable of efficient interaction with an electron beam during start up process. Starting current of several modes is below the operating current for all operating values of beam energy, see Fig.1. Presence of several modes leads to complicated processes of mode competition during start-up. Gyrotron design requires accurate simulations of start-up scenario to be able to control gyrotron operation at optimal efficiency at desired mode. Computationally efficient code, such as MAGY [2,3], is suitable for mode competition modeling during the long voltage rise time with respect to period of operating frequency.

This presentation devoted to recent development of MAGY model that allows effective simulations of start-up scenario in gyrotrons with dense mode spectrum, such as the FZK 170 GHz gyrotron. The development of new models is motivated by the needs of accurate modeling of mode competition involves six or eight modes. This includes modes both at fundamental and cyclotron harmonics.

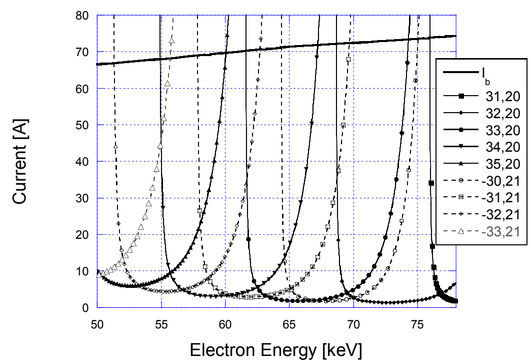

Fig. 1: Starting current of fundamental harmonic modes of the FZK 170 GHz gyrotron.

MAGY Models for Mode Interaction in Gyrotrons

Accurate simulations of mode competition process in gyrotrons with dense spectrum is challenging task even for the efficient code MAGY. Up to now there is no general computationally efficient solution for arbitrary number of modes with arbitrary indices and arbitrary frequencies. The recent development of the models is based on the most common patterns of mode competition in gyrotrons [4,5], namely triplet (or multiplet) of modes capable of parametric cross-excitation and doublet of modes with different azimuthal indices. The developed models allow for combination of triplets and doublets of modes to resolve main sequence of modes among large number of modes capable of self-excitation and competition.

Simulations of mode interaction processes involving large number of modes require models with large number of particles included in simulations. If number of particles is N for the single mode model, then it should be N^2 for the two of three modes and N^3 for six or eight modes to provide the same level of accuracy of simulations. A typical run time

for MAGY simulation at PC type computers (Pentium 4, 3.4 GHz) of start-up scenario (2.8 microseconds, 2800 time steps in simulations) is about 4 minutes for single mode, about 1 hour for three modes and about 18 hours for six modes for a moderate number of injected particles (*N=11*).

MAGY Simulations of Mode Competition in High Power Gyrotrons during Start-Up

MAGY is capable of simulations of mode interaction processes during long start-up process (from units to several hundred microseconds) in gyrotrons with dense spectrum, both with cylindrical and coaxial structures. MAGY can resolve excitation and competition of modes with a complex longitudinal profile. The example of longitudinal mode profile evolution during start-up is presented in Fig. 2. Different beam voltages correspond to a particular time during start-up.

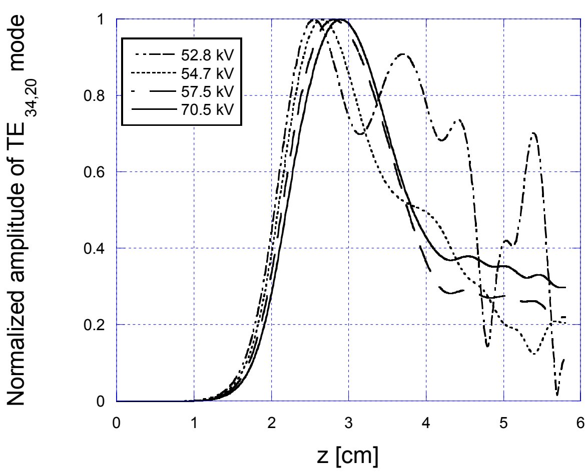

Fig. 2: Normalized longitudinal profile of operating mode for different voltages.

This presentation discusses the limitations of developed models for simulations of mode competition processes in gyrotrons with dense spectrum. Possible extensions of the developed models allowing for larger number of modes included in simulations are also presented.

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